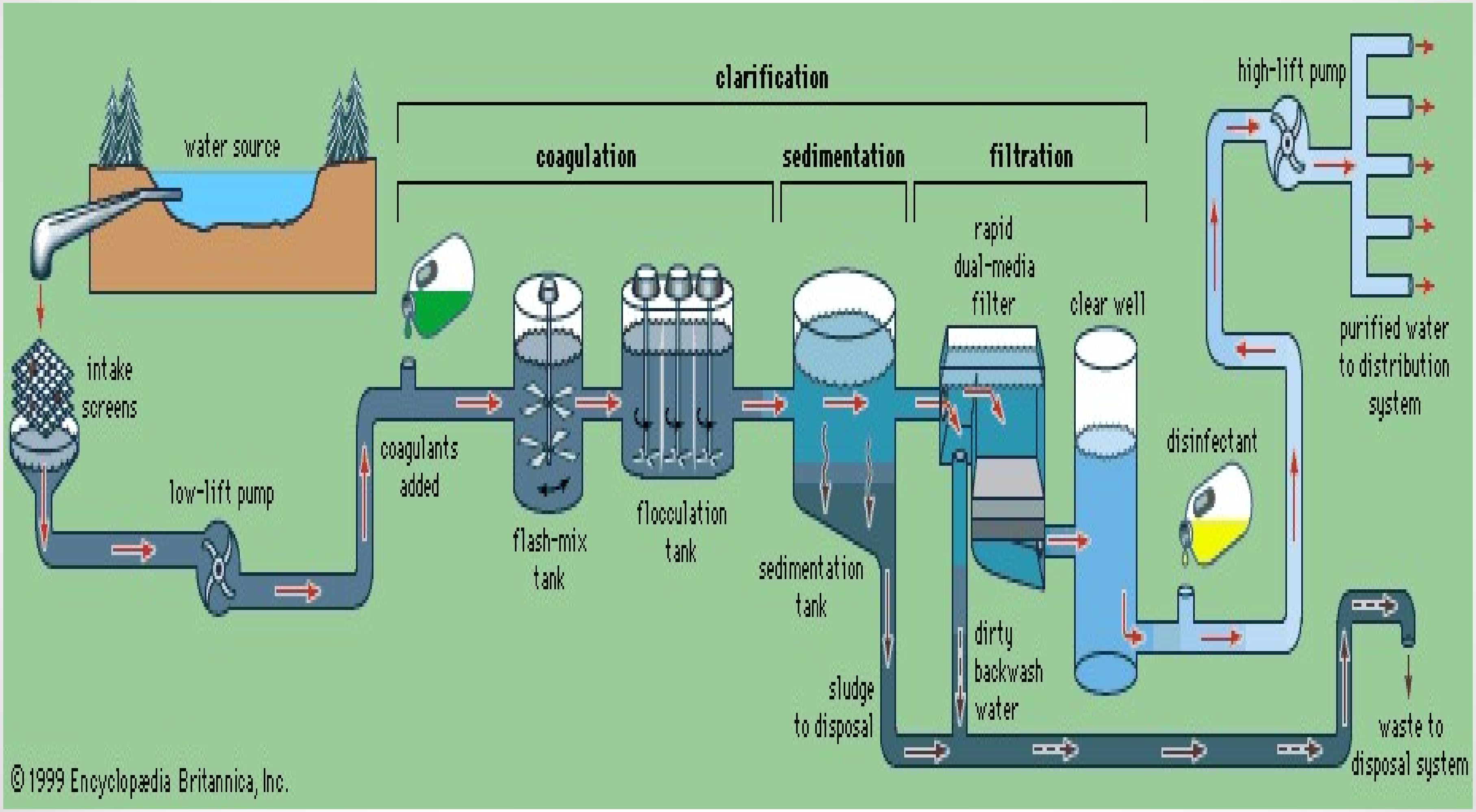
Waste Management and Treatment Technology – Part 1

Typical layout of a water treatment plant



The need to clarify water

- Public health
- Colloids – impart color and turbidity to water – extent of acceptability
- Microbes are colloids too

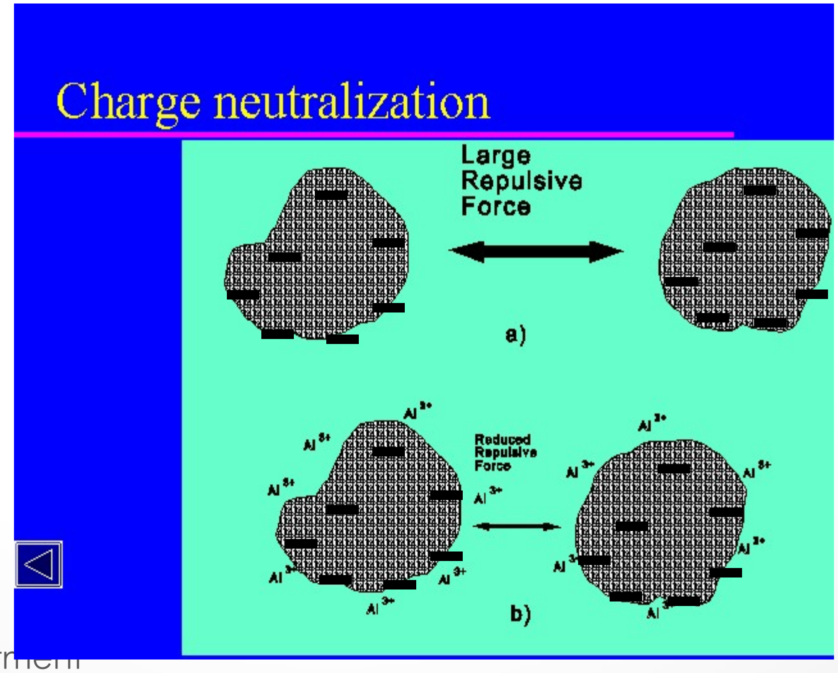
COAGULATION & FLOCCULATION

- **Removal of colloidal substances from water**

- **Potable water requirements**
- **Health, aesthetics, economic**
- **Colloids**
- **Size of colloids - light waves**
- **Brownian motion**
- **Stability of colloids**

What is Coagulation?

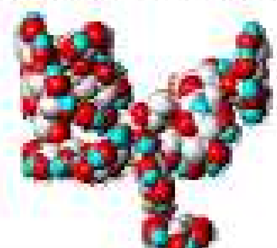
- **Coagulation** is the destabilization of colloids by addition of chemicals that neutralize the negative charges
- The chemicals are known as coagulants, usually higher valence cationic salts (Al^{3+}, Fe^{3+} etc.)
- Coagulation is essentially a chemical process



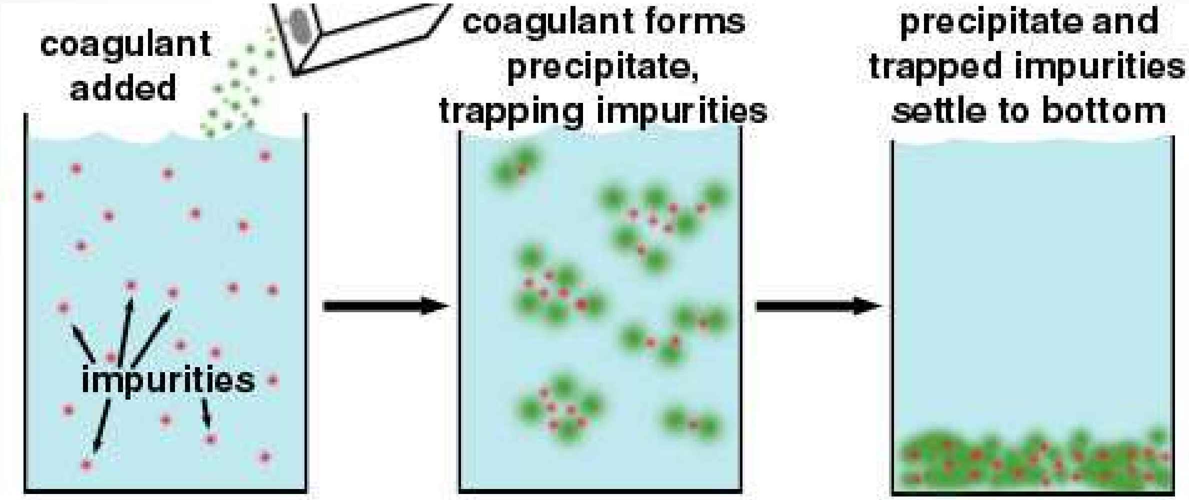
What is Flocculation?

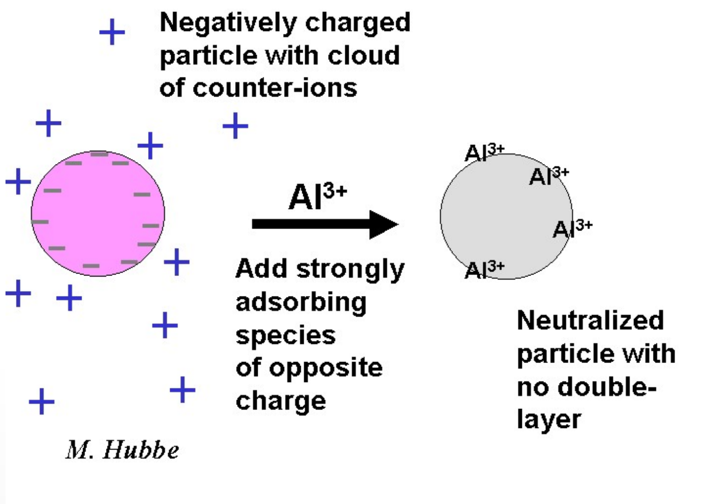
Flocculation is the agglomeration of destabilized particles into a large size particles known as flocs which can be effectively removed by sedimentation

- Gentle mixing or ***flocculation***, then causes the destabilized (reduced charge) colloids to cluster.
- Another method of enhancing agglomeration is to add organic polymers.
- These compounds consist of a long carbon chain with active groups such as amine, nitrogen, or sulfate groups along the chain.



Coagulation aim





Why coagulation and flocculation?

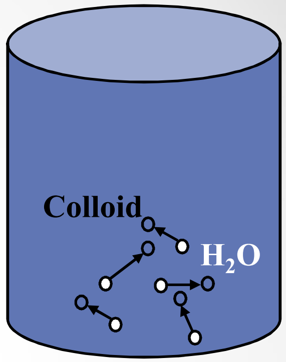
Various sizes of particles in raw water

Particle diameter (mm)	Type	Settling velocity
10	Pebble	0.73 m/s
1	Course sand	0.23 m/s
0.1	Fine sand	0.6 m/min
0.01	Silt	8.6 m/d
0.0001 (10 micron)	Large colloids	0.3 m/y
0.000001 (1 nano)	Small colloids	3 m/million y

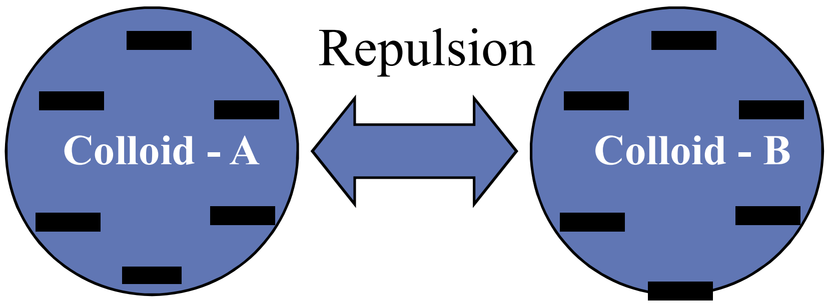
Gravity settling

Colloids – so small: gravity settling not possible

Colloid Stability



- ✓ Colloids have a net negative surface charge
- ✓ Electrostatic force prevents them from agglomeration



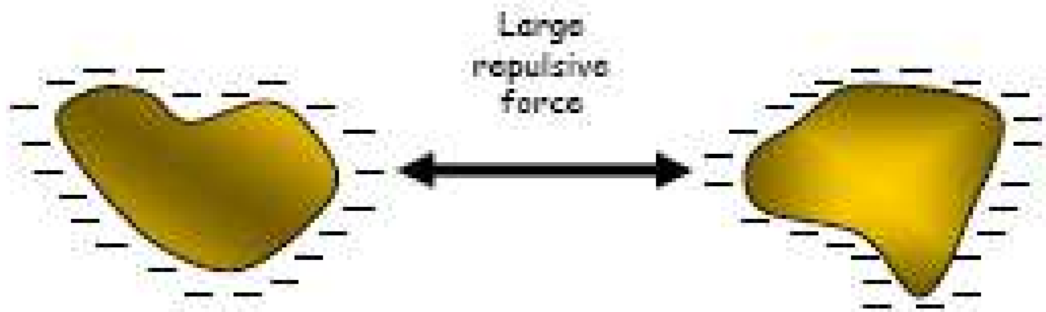
- ✓ Brownian motion keeps the colloids in suspension
- ✓ Impossible to remove colloids by gravity settling

Colloidal interaction

- There are two major forces acting on colloids:

1) electrostatic repulsion

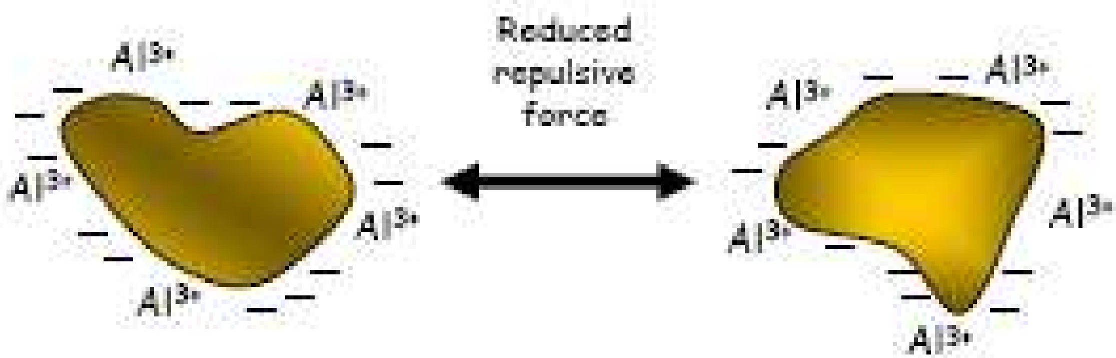
(simply, negative colloids repel other negatively charged colloids)



2) intermolecular, or van der Waals, attraction.

Charge reduction

- Coagulants can be used to reduce the electrostatic repulsive forces
- The electrostatic repulsion reduced by the addition of countercharged ions [Al^{3+}]

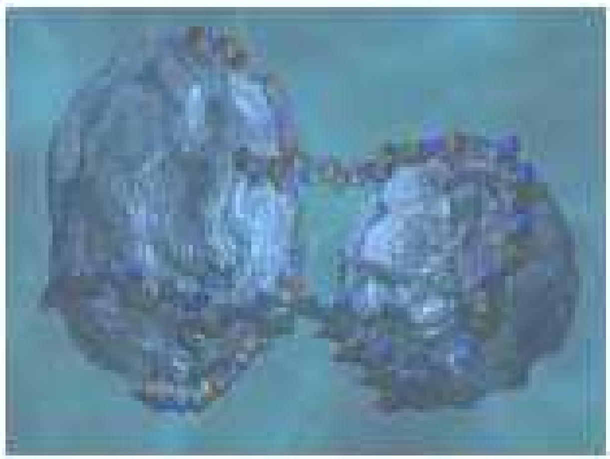


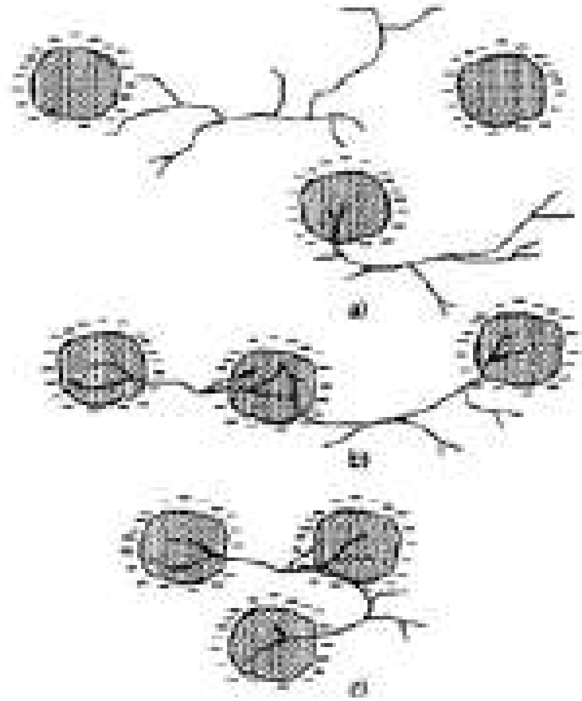
Colloid Destabilization

- **Colloids can be destabilized by charge neutralization**
- **Positively charges ions (Na^{+}, Mg^{2+}, Al^{3+}, Fe^{3+} etc.) neutralize the colloidal negative charges and thus destabilize them.**
- **With destabilization, colloids aggregate in size and start to settle**

Flocculation aids

- The chain is long enough to allow active groups to bond to multiple colloids





Floc formation with polymers

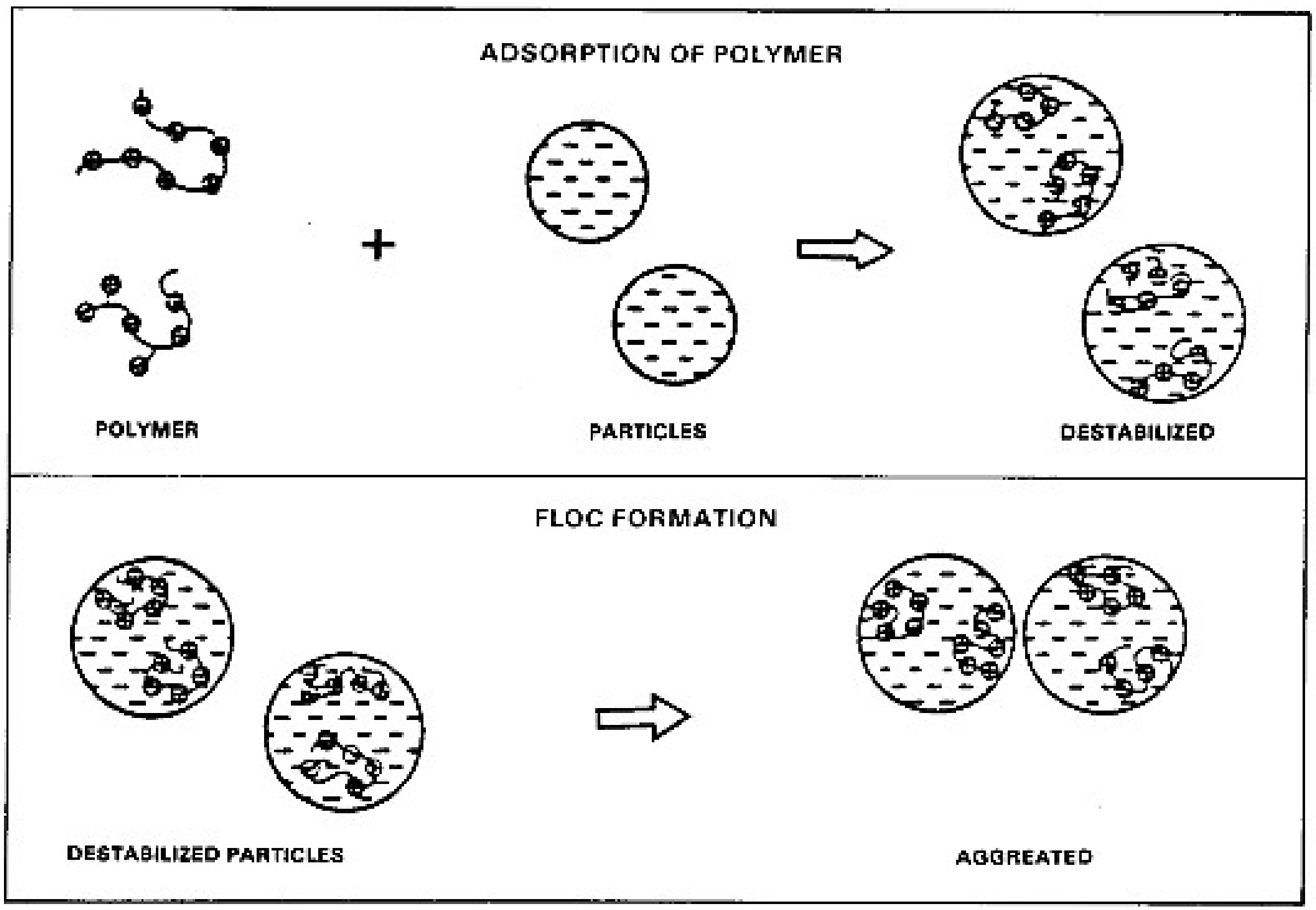


Figure 1-2. Floc formation process

Jar Tests

- The jar test – a laboratory procedure to determine the optimum pH and the optimum coagulant dose

- A jar test simulates the coagulation and flocculation processes

Determination of optimum pH

- Fill the jars with raw water sample (500 or 1000 mL) – usually 6 jars

- Adjust pH of the jars while mixing using H_2SO_4 or NaOH/lime
(pH: 5.0; 5.5; 6.0; 6.5; 7.0; 7.5)

- Add same dose of the selected coagulant (alum or iron) to each jar
(Coagulant dose: 5 or 10 mg/L)

Jar Test

Jar Tests – determining optimum pH

- ❑ Rapid mix each jar at 100 to 150 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container

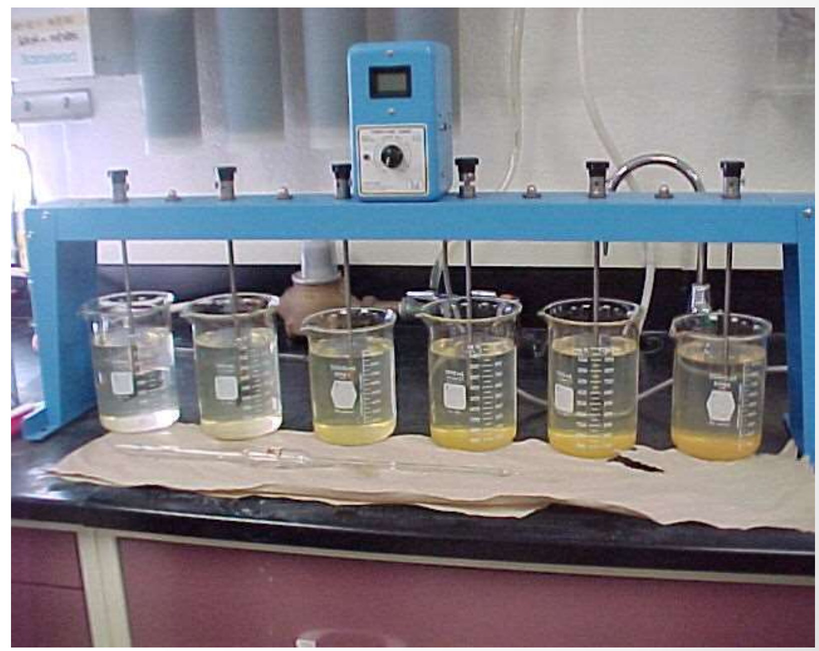
- ❑ Reduce the stirring speed to 25 to 40 rpm and continue mixing for 15 to 20 mins
This slower mixing speed helps promote floc formation by enhancing particle collisions, which lead to larger flocs

- ❑ Turn off the mixers and allow flocs to settle for 15 to 30 mins

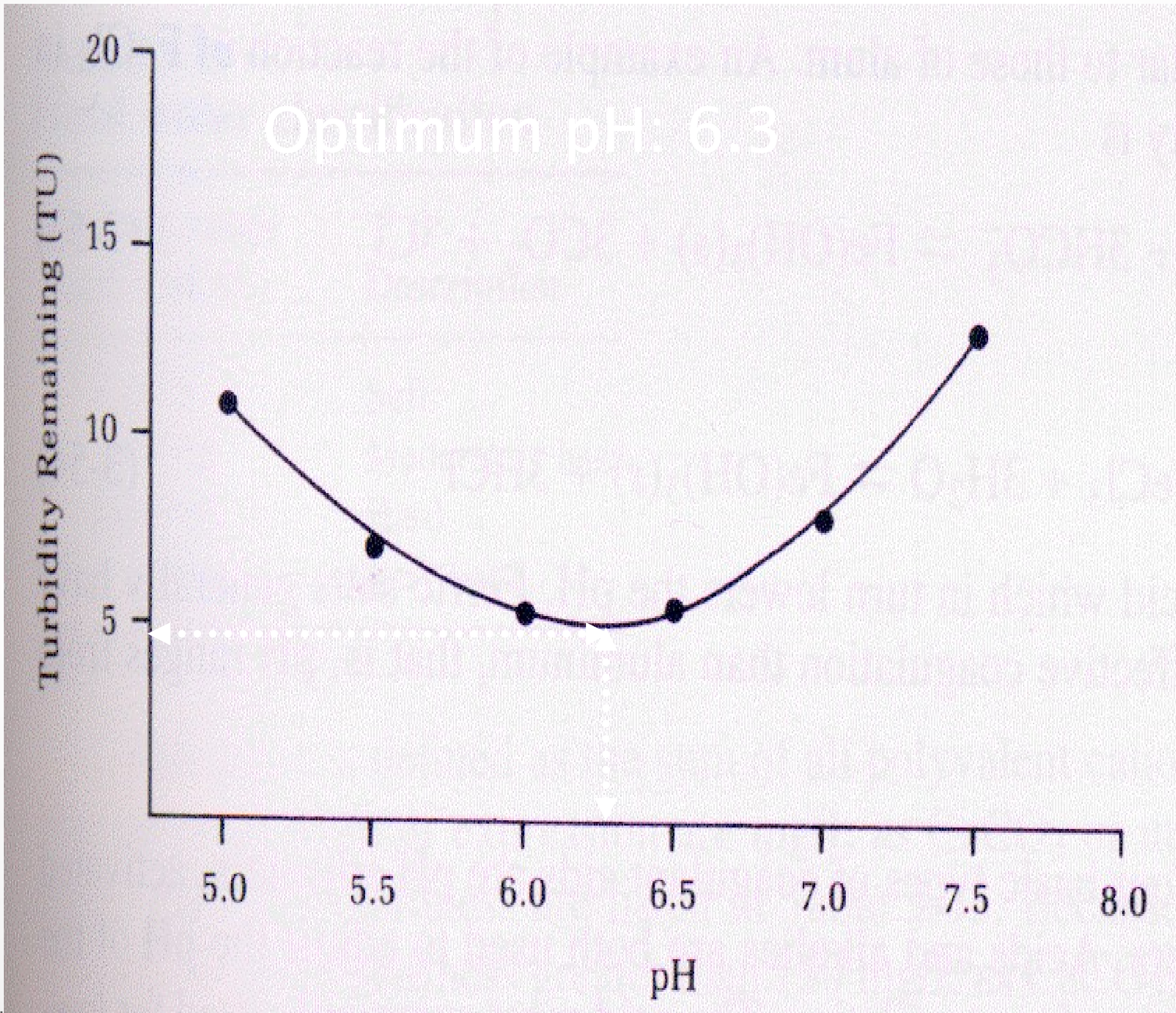
- ❑ Measure the final residual turbidity in each jar

- ❑ Plot residual turbidity against pH

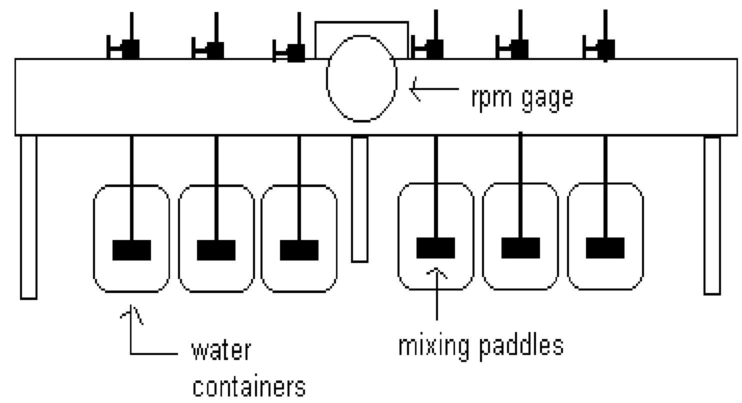
Jar Test set-up



Jar Tests – optimum pH



Optimum coagulant dose

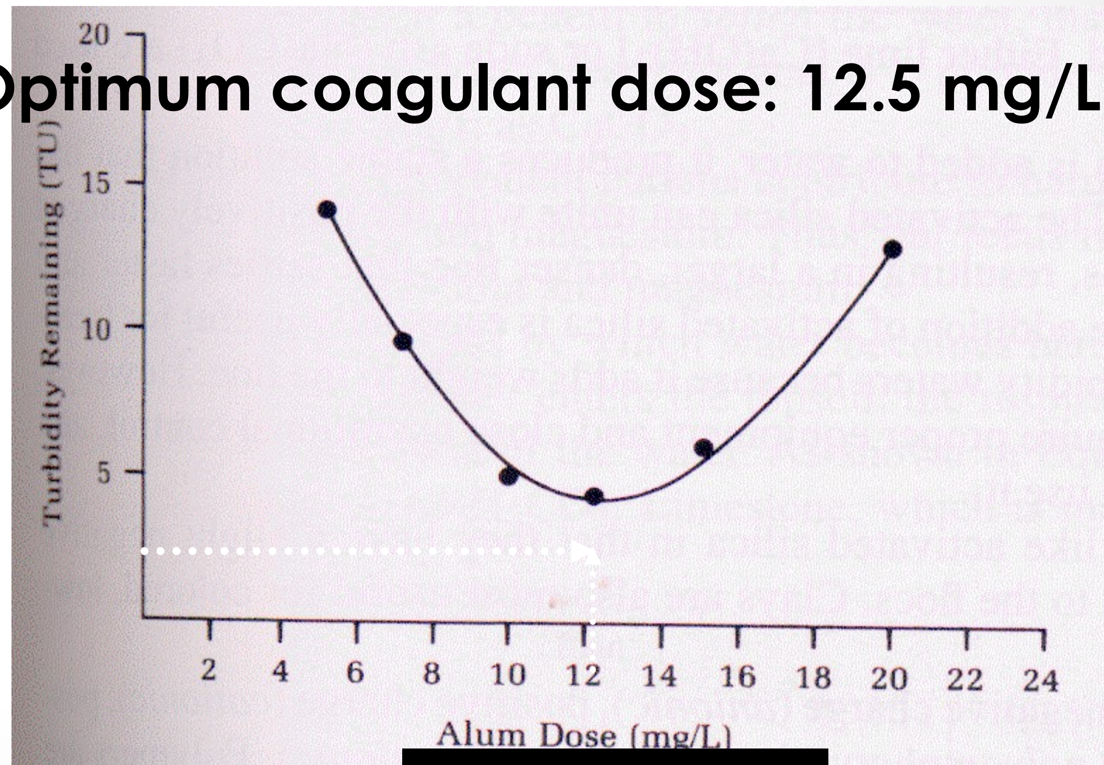


- Repeat all the previous steps
- This time adjust pH of all jars at optimum (6.3 found from first test) while mixing using H_2SO_4 or NaOH/lime
- Add different doses of the selected coagulant (alum or iron) to each jar (Coagulant dose: 5; 7; 10; 12; 15; 20 mg/L)
- Rapid mix each jar at 100 to 150 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container
- Reduce the stirring speed to 25 to 30 rpm for 15 to 20 mins

Optimum coagulant dose

- ❑ Turn off the mixers and allow flocs to settle for 30 to 45 mins
- ❑ Then measure the final residual turbidity in each jar
- ❑ Plot residual turbidity against coagulant dose

Optimum coagulant dose: 12.5 mg/L



Coagulant Dose mg/L

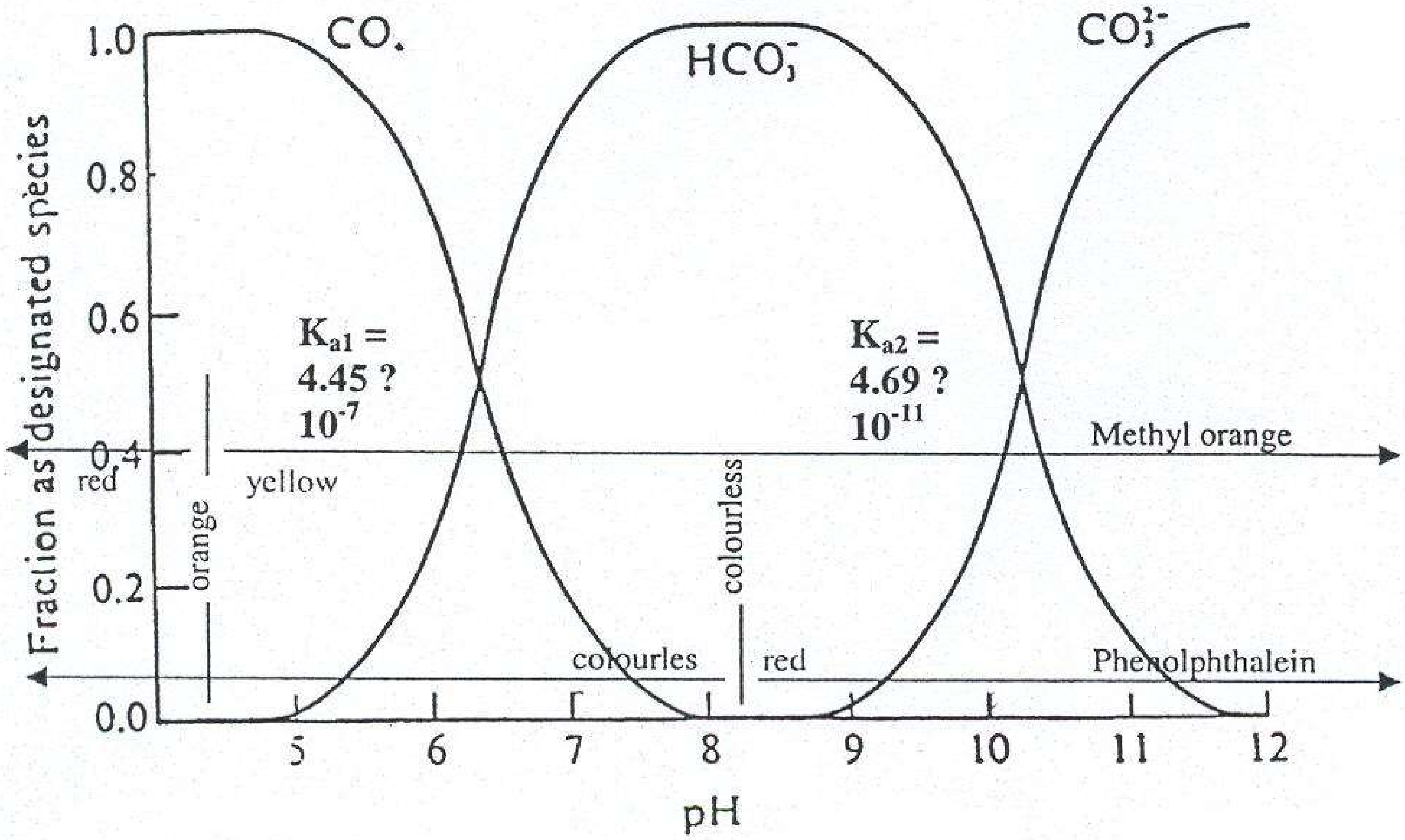
The coagulant dose with the lowest residual turbidity will be the optimum coagulant dose


Chemical feeding
Inflow

Alkalinity of Water Sample

- A measure of the ability of a water sample to act as a base by reacting with hydrogen ions.
- A measure of the capacity of the water body to neutralize acids and hence to resist acidification when acid rain falls into it.
- Sometimes refers as total alkalinity.

pH dependence of Carbonate species in water



Fraction of species for the $CO_2 - HCO_3^- - CO_3^{2-}$ system in water at different pH.

pH is changed by adding an alkali or an acid.

- Total alkalinity is the number of moles of H^+ requierd to titrate 1 liter of water sample to the end point.

- Total alkalinity = $2[CO_3^{2-}] + [HCO_3^-] + [OH^-] – [H^+]$
- The factor of 2 appears in front of carbonate ion concentration since the presence of H^+ it is first converted to bicarbonate ion, which is then converted to carbonic acid;

- Expressed as the mg/L of calcium carbonate equivalent

Exercise

- A water contains 100 mg/L CO_3^{2-} and 75.0 mg/L HCO_3^- at a pH of 10. Calculate its alkalinity.

Aluminum Chemistry

With alum addition, what happens to water pH?

$Al_2(SO_4)_3.14\ H_2O \Leftrightarrow 2Al(OH)_3 + 8H_2O + 3H_2SO_4$

1 mole of alum consumes 6 moles of bicarbonate (HCO_3^-)

$Al_2(SO4)_3.14\ H_2O + 6HCO_3^- \Leftrightarrow 2Al(OH)_3 + 6CO_2 + 14H_2O + 3SO_4^{2-}$

If alkalinity is not enough, pH will reduce greatly

Lime or sodium carbonate may be needed to neutralize the acid.

(Optimum pH: 5.5 – 6.5)

Alkalinity calculation

If 200 mg/L of alum to be added to achieve complete coagulation. How much alkalinity is consumed in mg/L as $CaCO_3$?

$$\underbrace{Al_2(SO_4)_3.14\ H_2O}_{594\ mg} + \underbrace{6HCO_3^-}_{366\ mg} \Leftrightarrow 2Al(OH)_3 + 6CO_2 + 14H_2O + 3SO_4^{-2}$$

594 mg alum consumes 366 mg HCO_3^-

200 mg alum will consume (366/594) x 200 mg HCO_3^-

= 123 mg HCO_3^-

Alkalinity in mg/L as $CaCO_3$ = 123 x (50/61)

= 101 mg/L as $CaCO_3$

Iron Chemistry

$FeCl_3 + 3HCO_3^- \Leftrightarrow Fe(OH)_3 + 3CO_2 + 3Cl^-$

With iron salt addition, what happens to water pH?
(Wider pH range of: 4 – 9; Best pH range of 4.5 – 5.5)

1 mole of $FeCl_3$ consumes 3 moles of bicarbonate (HCO_3^-)

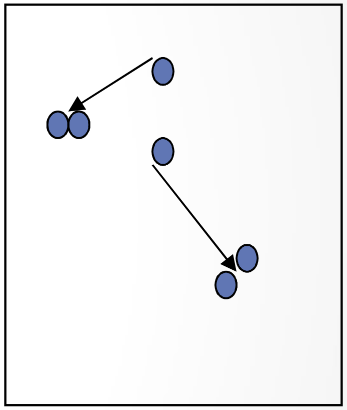
If alkalinity is not enough, pH will reduce greatly due to hydrochloric acid formation. Lime or sodium carbonate may be needed to neutralize the acid. Lime is the cheapest.

Flocculation: Purpose

- Promote agglomeration of particles into larger floc
- Units often designed on the basis of mixing intensity as described by the velocity gradient, G
  - some mixing is needed to keep particles in contact with other particles
  - too much mixing can cause floc break-up

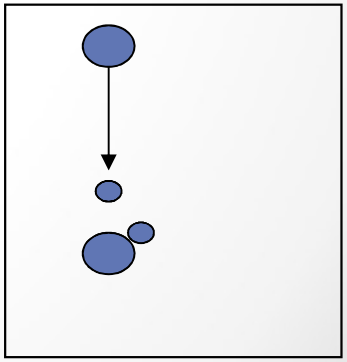
Design of Flocculator (Slow & Gentle mixing)

Flocculators are designed mainly to provide enough interparticle contacts to achieve particles agglomeration so that they can be effectively removed by sedimentation or flotation



Transport Mechanisms

- *Brownian motion*: for relatively small particles which follow random motion and collide with other particles (perikinetic motion)

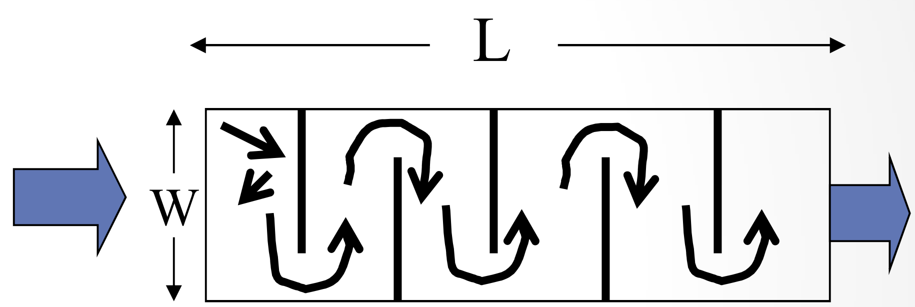


- *Differential settling*: Particles with different settling velocities in the vertical alignment collide when one overtakes the other (orthokinetic motion)

Hydraulic Flocculation

- *Horizontally baffled tank*

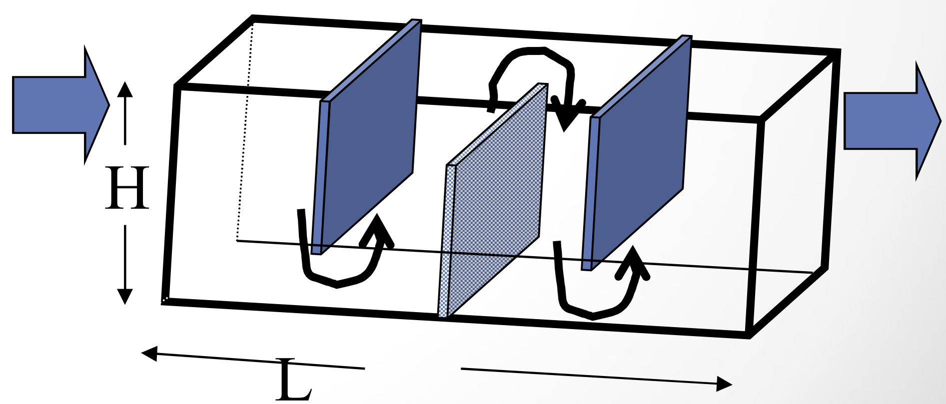
The water flows horizontally.
The baffle walls help to create turbulence and thus facilitate mixing



Plan view (horizontal flow)

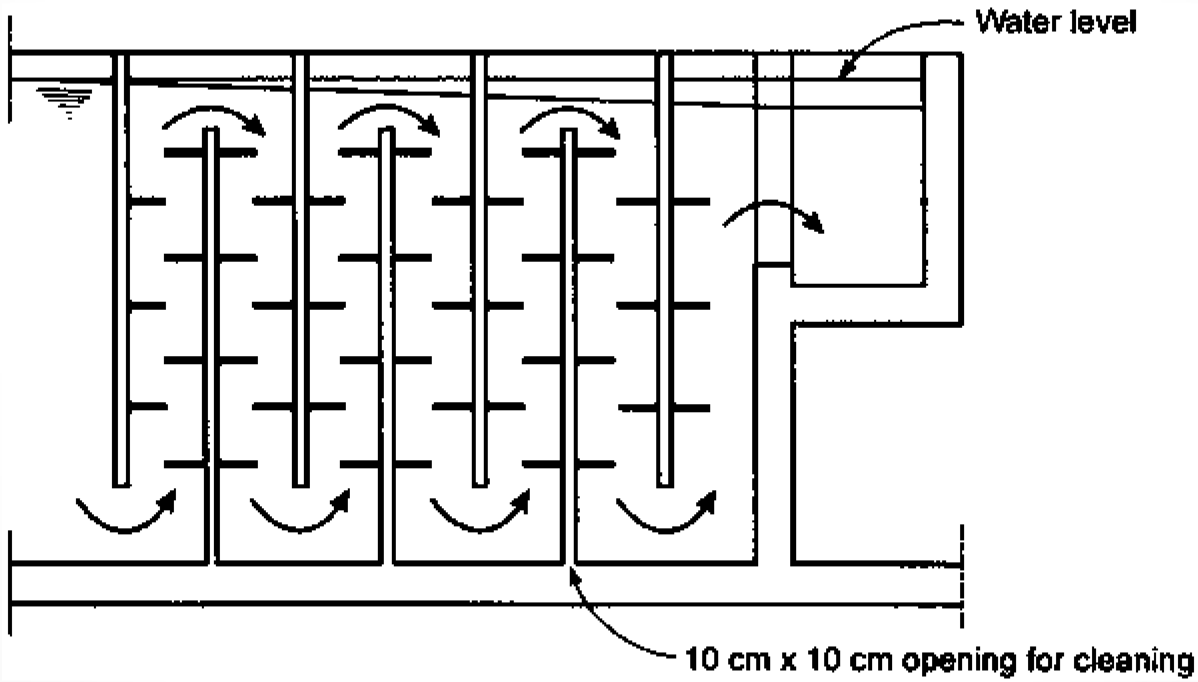
- *Vertically baffled tank*

The water flows vertically. The baffle walls help to create turbulence and thus facilitate mixing



Isometric View (vertical flow)

Hydraulic flocculators



Hydraulic Flocculation

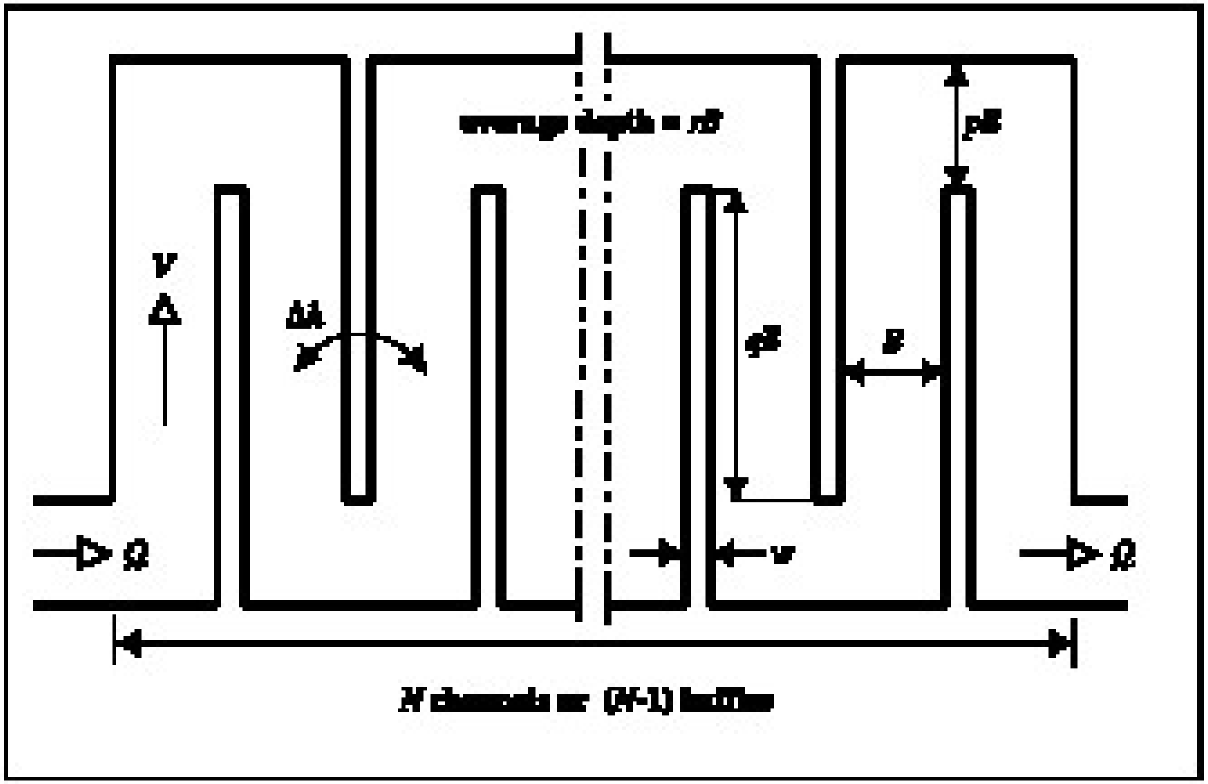
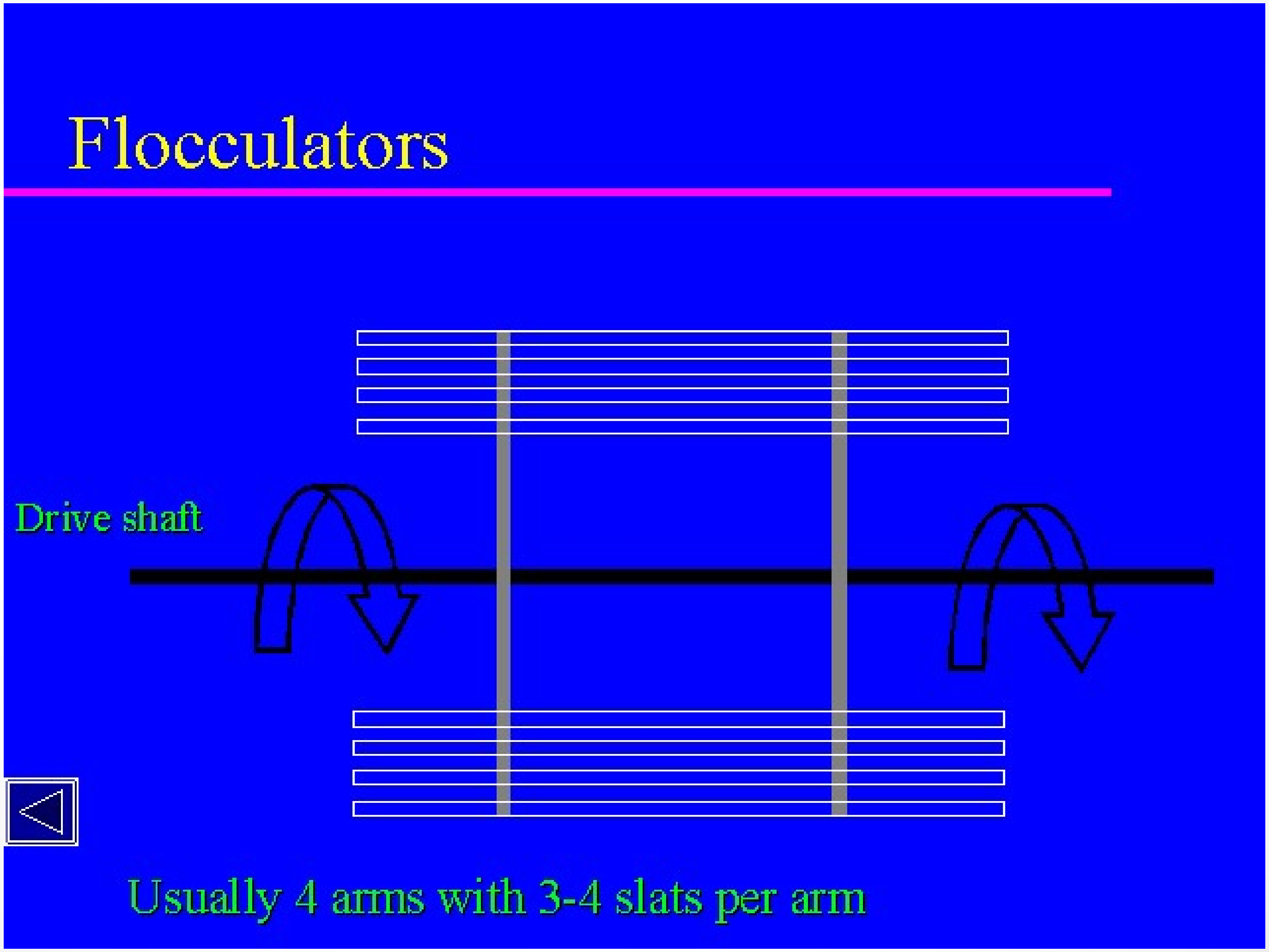


Figure 1 | Schematic layout of an around-the-end hydraulic flocculator, showing the notation used in this paper.

http://www.environmental-center.com/magazine/iwa/jws/art4.pdf

Hydraulic flocculators: simple technology

Hydraulic Flocculation:Large stirrers

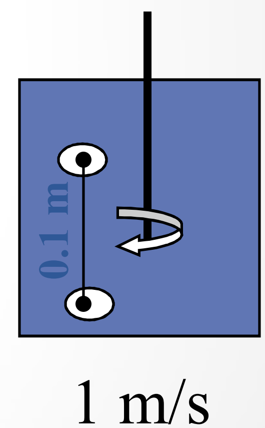


Mixing and Power

- *The degree of mixing is measured by* **Velocity Gradient (G)**
- **Higher G value, intenser mixing**

Velocity Gradient: relative velocity of the two fluid particles/distance

$$G = dv/dy = 1.0/0.1 = 10\ s^{-1}$$



In mixer design, the following equation is useful

$$G=\left[\frac{P}{V\mu}\right]^{1/2}$$

G= velocity gradient, s^{-1};
P = Power input, W
V = Tank volume, m^3;
μ = Dynamic viscosity, (Pa.s)

Flocculation: cont.

Power input

$$G = \left(\frac{P/V}{\mu} \right)^{0.5}$$

Tank volume

Dynamic viscosity

Extent of Mixing = Gt

VISCOSITY MEASUREMENT

Viscosity of water is a measure of its resistance to flow

The cgs unit is the Poise, 1 $gcm^{-1}s^{-1}$.
Water viscosity is c. $1cP = 0.01P = 0.001\ Pa.s$

$Pa = N/m^2$ *or* $kgms^{-2}m^{-2}$, *so* $Pa.s = kgms^{-2}m^{-2}s = kgm^{-1}s^{-1}$

This could also have been derived from going from $gcm^{-1}s^{-1}$, *multiplying by 100/1000.*

Therefore $1cP = 0.001kgm^{-1}s^{-1}$

WATER TREATMENT ENERGY CALCULATIONS

$F = ma$. In a gravity field, $F = mg$

Force in N, where a N is the force to accelerate 1kg @1m/s^2

Force to move h, Potential energy = $Fh = mgh$

Dimensions kgm^2s^{-2} = Nm or J

Rate of energy usage, or power, $P = mgh/t$

Dimensions are now ML^2T^{-3}, or kgm^2s^{-3} = J/s or W.

Power (W) to pump water to h, flow rate in kg/s

$W = kg/s \times h \times 9.8\ m/s^2$

kW, divide by 1000 HP, divide by 746

- **G value for coagulation: 700 to 1000 S^{-1}; 3000 to 5000 S^{-1} for in-line blender; 1-2 sec**
  Mixing time: 30 to 60 S

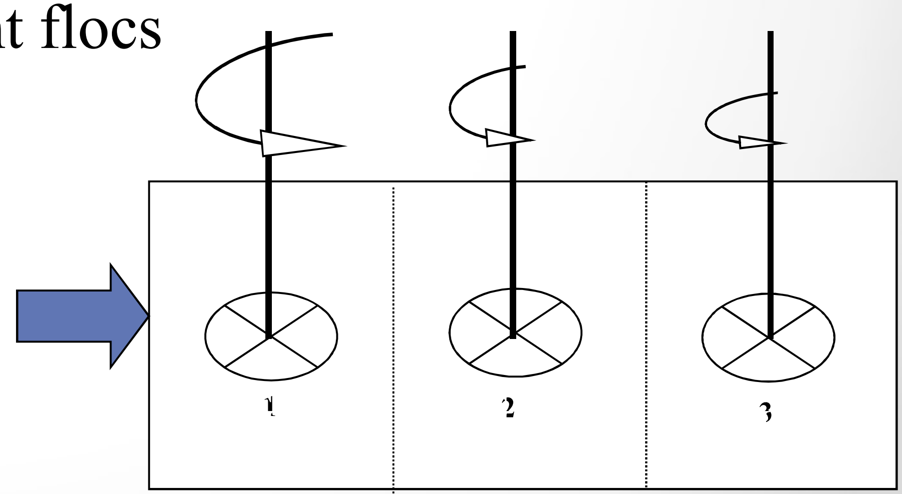
- **G value for flocculation: 20 to 80 S^{-1};**
  Mixing time: 20 to 60 min

In the flocculator design, Gt (also known Camp No.); a product of G and t is commonly used as a design parameter

Typical Gt for flocculation is 2 x 10^4 - 10^5

Large G and small T gives small but dense floc
Small G and large T gives big but light flocs

We need big as well as dense flocs which can be obtained by designing flocculator with different G values



Power Calculation

What horsepower level do we need to supply to a flocculation basin to provide a G value of $100 s^{-1}$ and a Gt of 100,000 for $0.438 m^3/sec$ flow? **(Given:** $\mu = 0.89 \times 10^{-3}$ Pa.s; 1 hp = 745.7 watts)

Solution:

Retention time, t = Gt/G = 100,000/100 = 1000 secs

Volume of Flocculation basin, V = ($0.438\ m^3/sec$) x (1000 sec)
= $438\ m^3$

$$G = \left[\frac{P}{V\mu}\right]^{1/2}$$

$P = G^2 V \times \mu$
$= 100^2 \times 438 \times 0.89 \times 10^{-3}$ = 3900 W
= 3900/746 = 5.2 hp